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Two pixel computer generated hologram using a zero twist nematic liquid crystal spatial light modulator

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Abstract

We present a method of producing a computer-generated hologram using a zero twist linear nematic liquid crystal spatial light modulator. A 2x1 macro pixel method is used, one pixel representing the real data, and one the imaginary. A method is shown that produces both positive and negative analogue amplitude modulation.

Introduction

Zero twist nematic liquid crystal (ZTNLC) (also known as planar nematic) spatial light modulators (SLMs) are usually used to modulate light in a phase only mode. By selecting the correct input polarisation state, the device will act as if its refractive index is electronically modulated. Such devices have been used in adaptive optics, diffractive optical elements, and optical correlators. However, since the devices are birefringent they can also be used as amplitude modulators if the input polarisation state is linear and at 45° to the extraordinary axis. Using this configuration it is also possible to obtain positive and negative amplitude modulation, i.e., the device can modulate along the real axis. By combining two pixels together, full complex modulation is possible using a phase detour technique. This method of complex modulation is similar to that used by Lee¹ and others², but only requires two pixels instead of 4, making it more suitable for computer generated hologram production on an SLM where the number of pixels are limited. Other techniques have been used such as cascading two SLMs³ and using deformable mirror devices⁴.

Theory

If the device is set up in single pass mode with its extraordinary axis vertical, an SLM pixel is represented by the Jones matrix:

$$\mathbf{L} = \begin{pmatrix} \exp(-i\Gamma/2) & 0 \\ 0 & \exp(i\Gamma/2) \end{pmatrix} \quad [1]$$

where Γ is the retardance of the SLM pixel. If the input polarisation state is linear and at 45° and the output polariser is also at 45° , we obtain

$$\frac{1}{2} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} \exp(-i\Gamma/2) & 0 \\ 0 & \exp(i\Gamma/2) \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \begin{pmatrix} \cos \Gamma/2 \\ \cos \Gamma/2 \end{pmatrix} \quad [2]$$

Which give amplitude modulation from 1 to -1 for $\Gamma=0$ to 2π . However, the current trend in the manufacture of ZTNLC SLMs is to build them onto a silicon backplane. This makes the device double pass. It is not adequate to merely double the value of Γ in equation [1] since a co-ordinate transform has also occurred. The correct Jones matrix for the SLM in reflection is given by⁵

$$\mathbf{J} = \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \mathbf{L}^t \mathbf{L} \quad [3]$$

where \mathbf{L}^t is the transpose of \mathbf{L} .

The system in double pass is now given by

$$\frac{1}{2} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} -\exp(-i\Gamma) & 0 \\ 0 & \exp(i\Gamma) \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \begin{pmatrix} i \sin \Gamma \\ i \sin \Gamma \end{pmatrix} \quad [4]$$

which is still equivalent to modulating along the real axis since the overall phase shift introduced by the i in equation [4] can be neglected. The intensity and phase modulation are shown in figure 1.

Complex modulation is achieved by placing the real data on a pixel next to the imaginary data. The data is thus arranged in to a 2x1 macro pixel. The sign of every second macro pixel must be reversed (see figure 2) to produce a constant phase delay. The complex reconstruction then occurs at an angle such that there is $\pi/2$ phase lag between the pixel representing the real data and the pixel containing the imaginary data. The sign reversal is necessary to remove the π phase step that would otherwise occur.

Experimental

The SLM used was a 128x128 ZTNLC SLM from Boulder Nonlinear Systems, Inc. The device has a pixel size of 40 μ m and a fill factor of 60%. The device has 8 bit (256 levels) resolution and a liquid crystal response time of about 2ms (depending on temperature).

The SLM was calibrated by measuring the intensity throughput of the SLM for various voltages applied using the system shown in figure 3. A 638.2nm He-Ne laser was used as the light source. The SLM is capable of producing 2π radians phase shift at this wavelength. The results for the intensity calibration are shown in figure 4. A polynomial was then fitted to the data from SLM value 0 to the first turning point, and another polynomial was fitted to the data from the last turning point on figure 4 to the SLM value 256. The since each region was π out of phase with each other, the first polynomial was used to represent the negative values, and the second the positive values. A fast Fourier transform of the letter P (slightly off axis) was then performed on a PC. This complex data was then arranged into 2x1 macro pixels as described above. This means there is a different sampling rate for each direction and the output field is not a square. The data was then passed through the calibration polynomials and written to the SLM. The CCD camera in figure 3 digitised the resulting reconstruction shown in figure 5. Blanking the imaginary data leads to a conjugate image appearing in the reconstruction (see figure 6).

Discussion

Full complex modulation has been demonstrated using the ZTNLC SLM. The reconstruction appears off axis in figures 5 and 6 because of the phase wedge introduced into the system. The reconstruction is in fact quarter of the way between the zeroth and first order.

There is also a dc term visible. The dc term is not inherent to the method but comes from calibration errors and unmodulated reflections from the front glass plate of the SLM. The on axis dc term can be calculated by the integral of the input function. Since this method can produce positive and negative modulation, this integral can be zero. This differs from the Lee¹ technique where there is a large dc bias. The dc terms could probably be reduced by carefully calibrating each pixel of the SLM. Interferometric analysis of the SLM shows that there is a non-uniform response across the device, which is likely to be from the device being of non-uniform thickness. The faceplate over the SLM has a broad band antireflection coating on it; the amount of reflections from this could be reduced by using a narrow band coating, suitable for the specific laser used.

The 2x1 macro pixel format means that there is a reduction in resolution in one dimension. The low quality of the reconstruction is likely to come from the non-uniform response of the SLM and the low number of pixels used. The quality of the reconstruction could be improved if a larger resolution device was used. A 512x512 will shortly be available from Boulder Nonlinear Systems.

Conclusions

Full complex modulation with a nematic liquid crystal spatial light modulator has been demonstrated. Two pixels were combined together, one representing the real data and one the imaginary. Methods for producing positive and negative modulation have been shown.

Acknowledgements

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Figure Captions

Figure 1) The left hand graph shows the phase shift (in radians) created by a double pass ZTNLC SLM as the retardance increases (units radians). The right hand graph shows the corresponding intensity transmission.

Figure 2) The method of producing a full complex modulation from two pixels.

Figure 3) The experimental setup. BS: beam splitter, POL: polariser

Figure 4) The calibration graph for the ZTNLC SLM.

Figure 5) The reconstruction of the hologram.

Figure 6) The reconstruction of the real only part of the hologram.

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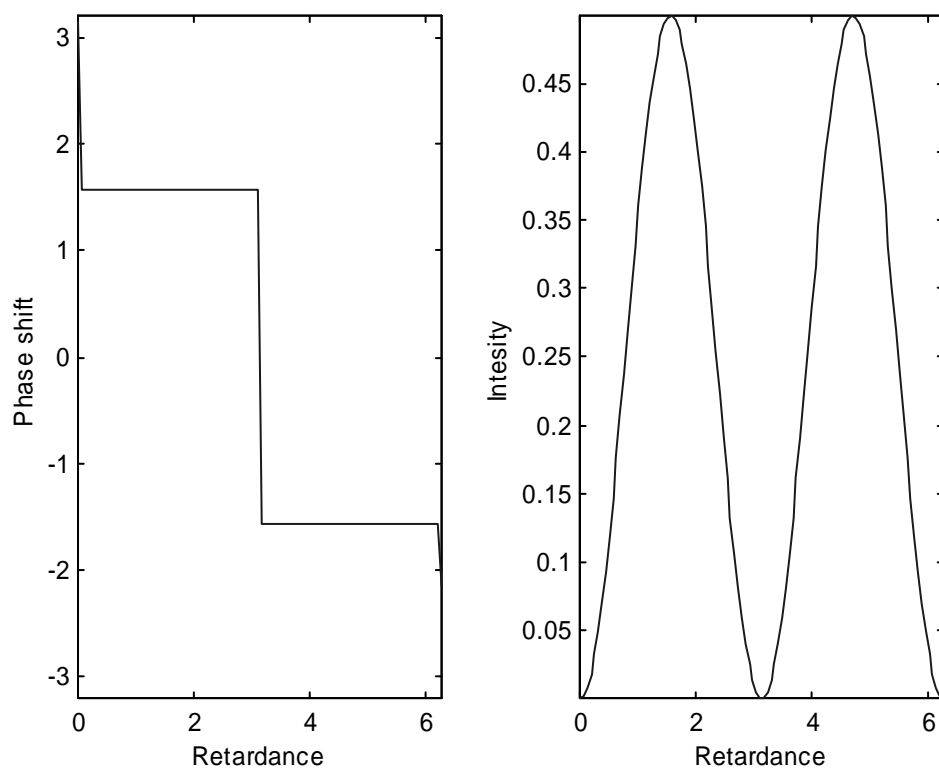


Figure 1

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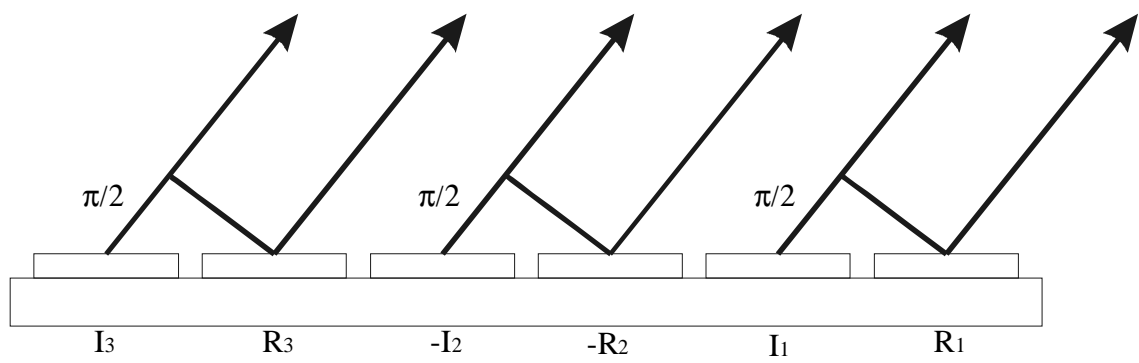


Figure 2.

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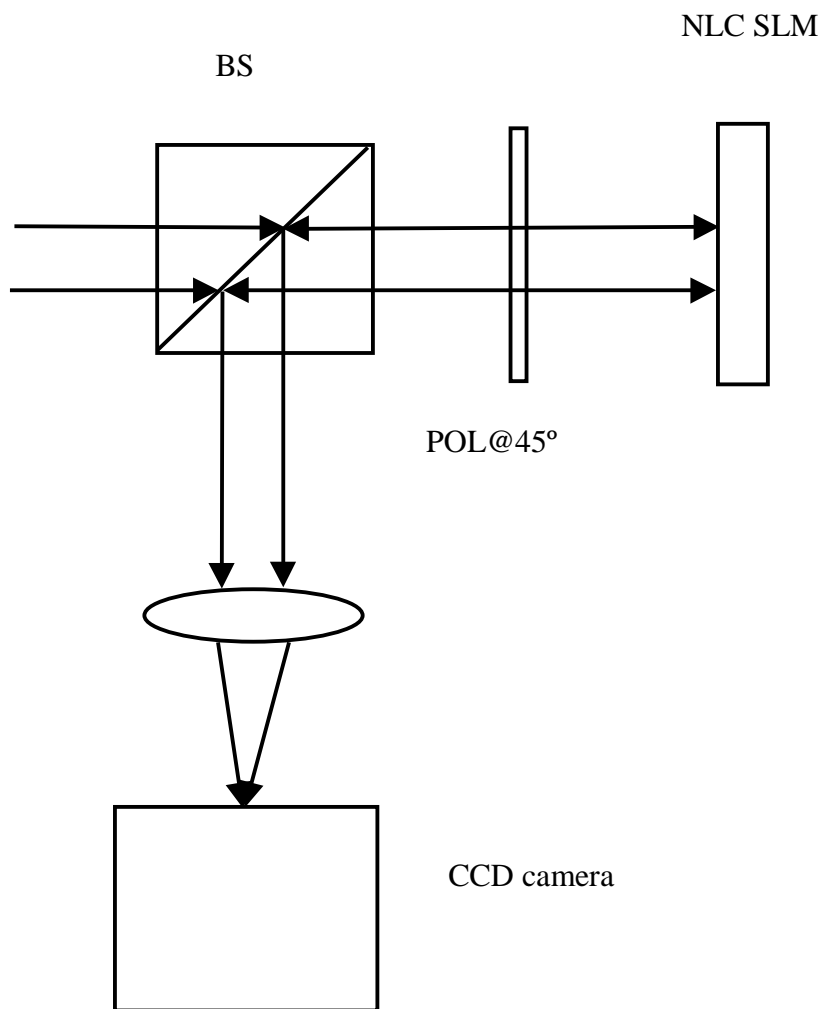


Figure 3

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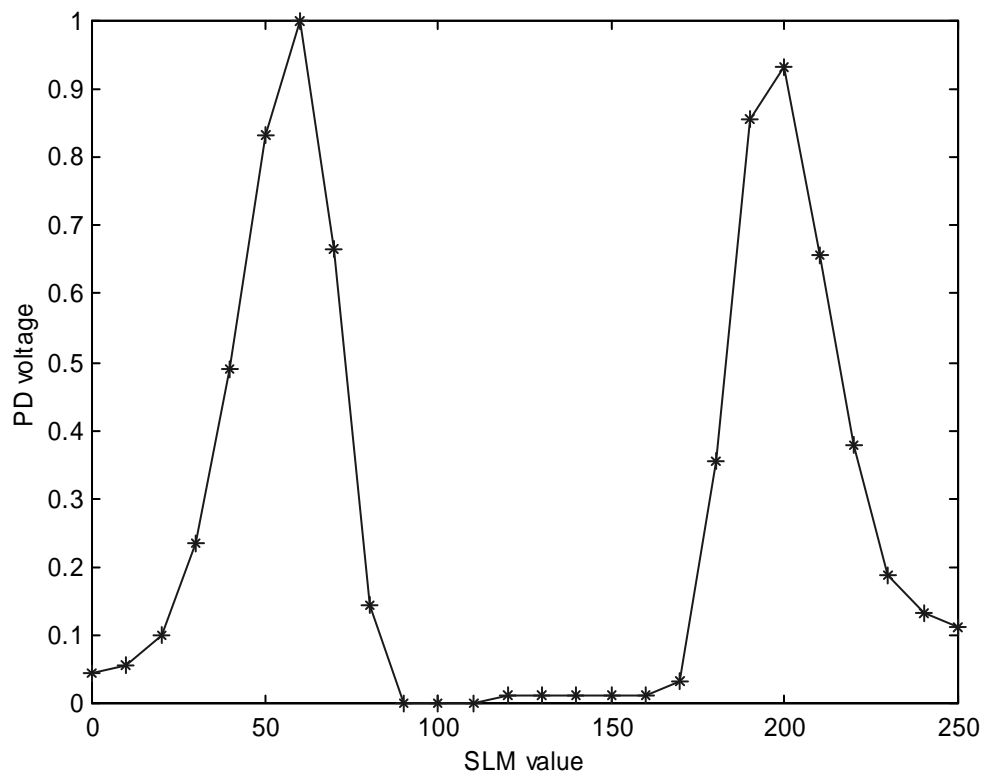


Figure 4

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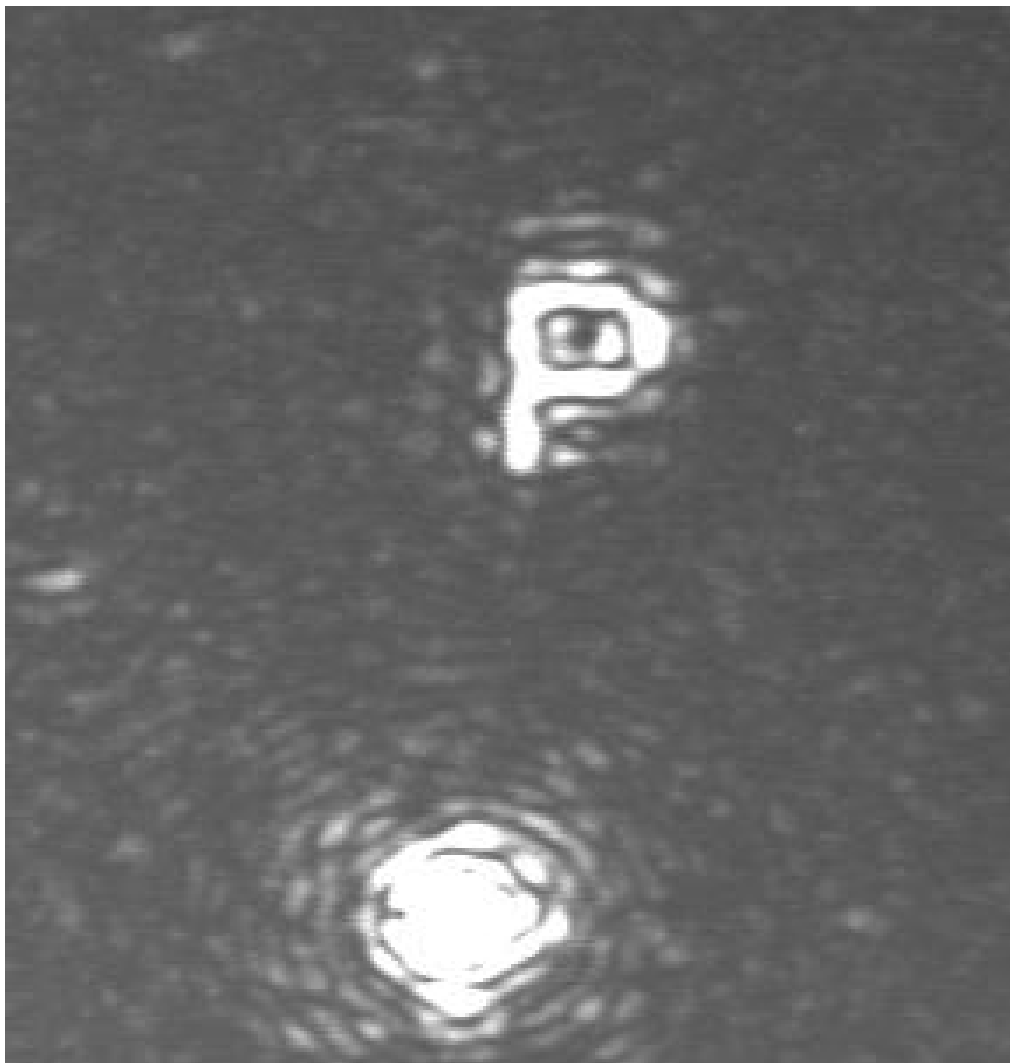


Figure 5

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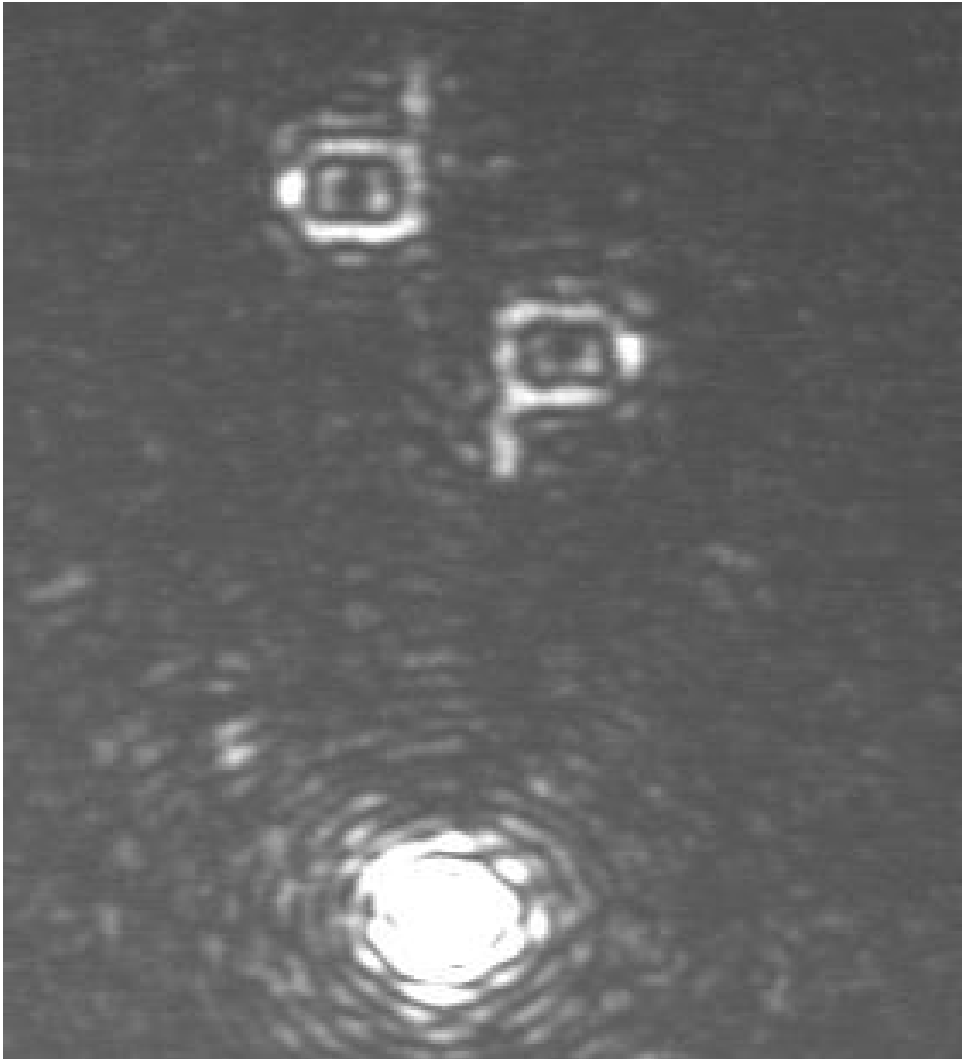


Figure 6

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